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## The Concentration of Forest Tree Roots in the Surface Zone of Some Piedmont Soils

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## The Concentration of Forest Tree Roots in the Surface Zone of Some Piedmont Soils\*

By WAYNE H. SCHOLTES

### INTRODUCTION

The location and amount of small roots in a forest soil are of interest, because the small roots afford an approximation of the water absorbing surfaces of trees. Small roots occur profusely in branches and mats from the main lateral roots and tend to concentrate in the upper soil horizons. Referred to as "Feeding" roots by many, small roots are the means of moisture and nutrient intake from the soil.

It is of interest to evaluate the effect of soil properties upon the presence of small roots. The physical properties of the soil may possibly limit root growth through their effects on moisture conditions. Also, increasing age of forest stands might change physical characteristics of the soil and so influence moisture relations.

The object of this study was to measure the amount of small roots in the surface soil of a developmental and successional series of loblolly pine and shortleaf pine. The increase in number of small roots in the surface soil with increasing age of stands may be a significant factor in the establishment and development of reproduction in forest stands. Also, invading species with shallow roots may, in some cases, be excluded for the same reason.

### PREVIOUS WORK

Although there has been a great deal of work done upon the incidence and behavior of plant roots, there has been comparatively little done in an attempt to evaluate the change in amounts of small absorbing roots in the surface soil as forest stands develop.

### LOCATION OF SMALL ROOTS

Coile (1937) pointed out that the number of fine, absorbing roots in a forest stand increases rapidly until 20 or 30 years of age, and after 30 years the increase is much smaller. He also noted that the number of small roots in the lower horizons of the soil remained nearly constant after about the 20 year age class of pine.

Korstian and Coile (1938) found that the number of roots in the surface soil was much greater than in any other portion of the soil

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\*abstracted from a portion of the MS thesis, Duke University, 1940.

profile. This distribution was observed by other workers, namely Duncan (1935), Sprague (1933), Heyward (1933), Woodroof (1933), Cheyney (1927), Toumey and Kienholz (1931). These workers observed the same root distribution working in different portions of the country with grasses, shrubs and forest vegetation.

### Effects of Soils and Moisture

Studies of the effect of soil upon root development have led to conflicting ideas. Lutz *et al* (1937) concluded that branching of roots becomes more pronounced in fine textured soils and that coarse-textured material appeared unfavorable for root growth. Working with root systems in podzol soils in Russia, Kachinsky (1930) concluded that the mass of roots and their development is conditioned to a large extent by the soil. In Arizona, Haasis (1921) observed root systems of yellow pine seedlings and concluded that the finer the soil the larger is the root and the smaller the ratio between tops and root.

In contrast to the above findings, McQuilkin (1935) observed root development of pitch pine in New Jersey and came to the conclusion that on heavier soils root development tends to be less extensive. Rogers (1935) studied soil and root growth of fruit trees in England and found in coarse-textured soils the roots were long, thin and straight compared to short, stout roots in heavy textured soils. He deduced that soil would be utilized by the root system subject to limiting factors of (1) age and varietal habit of the plant, (2) mechanical factors such as hardness of the soil, (3) physical factors such as moisture, aeration and temperature, and (4) nutritional factors. Similar relationships of root development and limiting factors was also observed by Cannon (1915), Halden (1920), Holch (1931) and Lenhart (1934).

### Hereditary Influence

Several investigators such as Billings (1938), Coile (1940), Weaver and Kramer (1932), Toumey (1929), Anderson and Cheyney (1932), Kozlowski (1947), and Kozlowski and Scholtes (1948) have pointed out that root development under like environmental conditions will vary greatly according to species. Their studies showed that hardwoods generally have much more ramified root systems than conifers. Kozlowski and Scholtes (1948) also found that there were even more striking differences between root systems of various species in regards to numbers of root hairs and their total surface area. Like observations have also been made by Dittmer (1947) and Pavlychenko (1937) of crop plants.

The correlation between root development, soil moisture and the growth rate of different species was observed by Turner (1936), Stevens (1931), Reed (1939) and McDougal (1916).

#### METHODS OF STUDY

Since this study was concerned with tree roots in the surface soil, a shallow soil sampler 5.3 inches long by 3.29 inches wide, developed by Coile (1936), was used for sampling. Where roots occurred in the H layer or F layer, the organic layers were included in the sample. Otherwise organic layers were removed and the sample taken of mineral soil alone.

A convenient, arbitrary unit of ten samples from each forest stand was decided upon as the composite for study, each unit being based upon 7,382 cubic centimeters of soil. Under a well-stocked portion of each stand studied a grid was located at random using Tippet's numbers (1927). Individual samples were located by the grid in an area 90 feet by 150 feet or approximately one-quarter acre in area.

Throughout the study only loblolly pine stands of fine-textured soil (Georgeville silt loam) and shortleaf pine on coarse-textured soil (Whitestore sandy loam) were taken. This obviated any interaction of different soil types upon root development, and put stands within each type on similar levels. Species and soil in each forest type were combined throughout the study, and any separate effects of species on small roots lost in the interaction of species and soil.

For Whitestore sandy loam and Georgeville stony clay loam Korstian and Coile give average mechanical analysis figures (Table 1).

Although the soil in this study was Georgeville silt loam, their table of clay loam values gives a relative idea of the difference between the sandy loam and silt loam soils. Tabular values are somewhat higher in the clay fractions and correspondingly lower in the silt fractions than in ordinary silt loam soil.

**Table 1**  
Mechanical analysis of the Whitestore and Georgeville soil types.

Whitestore sandy loam					Georgeville stony clay loam				
Horizon	Depth in inches	% Sand	% Silt	% Clay	Horizon	Depth in inches	% Sand	% Silt	% Clay
A <sub>1</sub>	0-2	66.7	28.0	5.3	A <sub>1</sub>	0-2	21.1	41.4	37.5
A <sub>2</sub>	2-9	61.3	21.4	7.3	A <sub>2</sub>	2-5	20.4	44.0	35.6
B <sub>1</sub>	9-17	24.3	26.4	49.3	B	5-31	6.8	21.2	72.0
B <sub>2</sub>	17-33	22.6	52.9	24.5	C	31 +	29.0	47.0	24.0

For both species studied, loblolly pine and shortleaf pine, each age class was replicated in a different stand to minimize any differences due to local soil variations. Besides the two species of pine uneven aged stands of white oak-black oak-red oak were sampled and replicated in the coarse-textured and fine-textured soils. The values thus obtained located the upper portion of the regression of small roots in coarse-textured and in fine-textured soil. The "age" of these stands is figured at 320 years, because the succession from abandoned land to the hardwood climax would involve approximately such a period of time (Coile, 1940).

In the laboratory each composite sample was broken up, and roots removed from the soil by passing it, while moist, through 5 mm. and 2 mm. sieves. Moisture equivalents and wilting percentages were determined later on the 2 mm. soil. Roots were separated from the organic matter by spreading small quantities onto a white background and picking the roots from the debris with tweezers.

As roots were separated from the soil they were placed into diameter classes of: (1) less than 0.05 inch, (2) 0.05 to 0.10 inch, (3) 0.11 to 0.30 inch, (4) 0.31 to 0.50 inch, and (5) 0.51 to 1.0 inch. The roots were washed thoroughly to remove any soil and oven-dried for two days at 105 degrees C. After drying the roots were removed and weighed by size classes.

#### ANALYSIS AND RESULTS

Although the weight of roots larger than 0.10 were possibly correlated with increasing age of forest stands, an insufficient number of samples was taken to get values other than might be ascribed to chance. Therefore, attempts were confined to correlation of small roots with increasing age of forest stands.

Taking the data for root class 1, the small roots of less than 0.05

**Table 2**

Analysis of variance of the weight of roots less than 0.05 inch in diameter in the surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Variation due to	Degrees of Freedom	Mean Square	F
Types	1	0.22	
Within types			
Between age classes	15	8.03	2.77*
Error	17	2.89	
Total	33		

\*Significant at the 5 percent level.

inch in diameter, a statistical analysis was made to determine the effect of age of stand on root concentration in the surface soil (Table 2).

The  $F$ 's in the above table and in following analysis of variance tables represents the ratio of the larger mean square to the smaller mean square. If the observed  $F$  lies between the 5 percent and the 1 percent level, it is considered significant. If an observed  $F$  is above the 1 percent level, then it is considered highly significant (Snedecor, 1937).

Table 2 shows there is no significant difference due to types, or that no species exhibits a significant difference over the other in the weight of small roots. However, the observed  $F$  of between age classes is significant and indicates that there are differences in weights of small roots between age classes within each type.

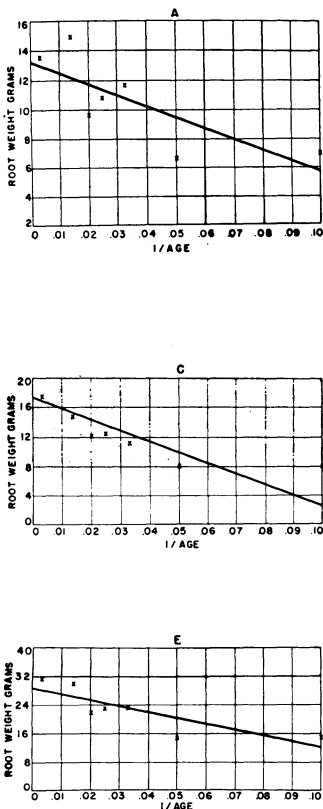


FIGURE 1. REGRESSION OF WEIGHT IN GRAMS OF ROOTS IN 7382 CC OF SURFACE SOIL ON THE RECIPROCAL OF THE AGE OF LOBLOLLY PINE STANDS. A—ROOTS LESS THAN 0.05 INCH IN DIAMETER, B—ROOTS 0.05 TO 0.10 INCH IN DIAMETER, C—ROOTS 0.10 TO 0.15 INCH IN DIAMETER, D—ROOTS 0.15 TO 0.20 INCH IN DIAMETER, E—ROOTS 0.20 TO 0.25 INCH IN DIAMETER.

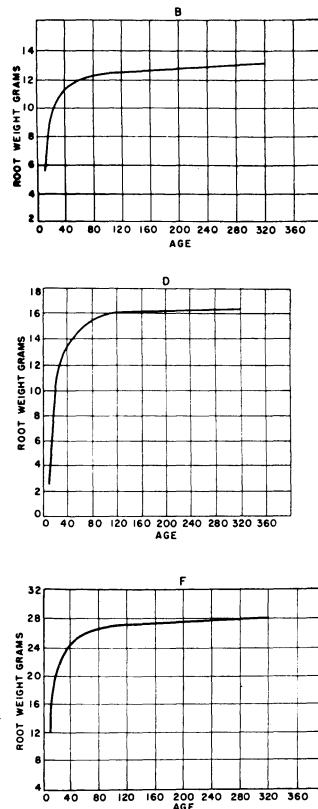


FIGURE 2. REGRESSION OF WEIGHT IN GRAMS OF ROOTS IN 7382 CC OF SURFACE SOIL ON AGE OF LOBLOLLY PINE STANDS. B—DERIVED FROM FIGURE 1A, D—DERIVED FROM FIGURE 1C, F—DERIVED FROM FIGURE 1E.

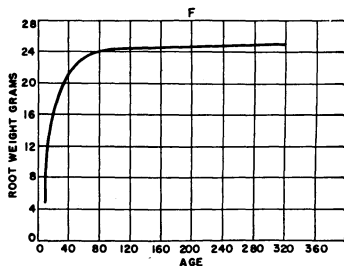
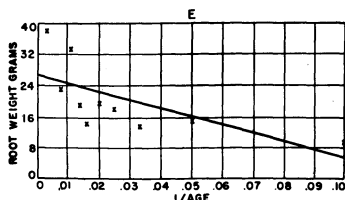
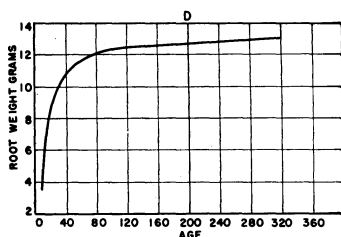
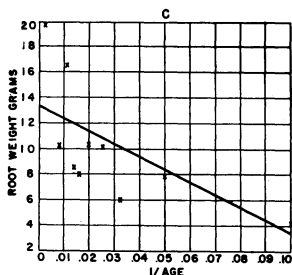
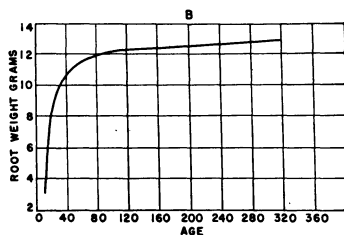
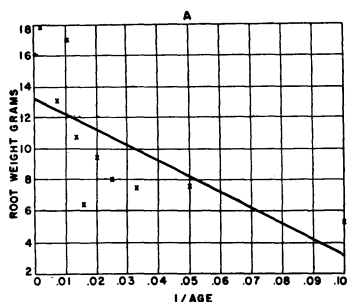


FIGURE 3. REGRESSION OF WEIGHT IN GRAMS OF ROOTS IN 73% CO OF SURFACE SOIL ON THE RECIPROCAL OF THE AGE OF SHORTLEAF PINE STANDS. A—ROOTS LESS THAN 0.05 INCH IN DIAMETER. C—ROOTS 0.05 TO 0.10 INCH IN DIAMETER. E—ALL ROOTS UP TO 0.10 INCH IN DIAMETER.

FIGURE 4. REGRESSION OF WEIGHT IN GRAMS OF ROOTS IN 73% CO OF SURFACE SOIL ON AGE OF SHORTLEAF PINE STANDS. (B DERIVED FROM FIGURE 3A. D DERIVED FROM FIGURE 3C. F DERIVED FROM FIGURE 3E.)

The data for root class 1 were separated into the shortleaf pine and loblolly pine types, and the root weights plotted over the age of the forest stand. As might be expected the points were scattered and would not form a smooth curve, because insufficient replications were made to average out variations due to local conditions.

In order to obtain a smooth curve from the data the root weights were plotted over the reciprocal of age, and a straight line was fitted to the data by the method of least squares (Figs. 1A and 3A). From the straight line relationship a curve of root-weight over age was obtained (Figs. 2B and 4B) for the loblolly pine and the shortleaf pine types.

Figures 2B and 4B depict the trend of small roots in the two pine types and show that the amount of small, fibrous roots increases very rapidly until the stand reaches about 30 years of age. After this time the small roots increase slowly, and as the stand approaches maturity the surface soil reaches an approximate saturation of small roots.

Comparison of the curves of root-weight over age for roots less than 0.50 inch in diameter show the same trend in both species. However, the curve for loblolly pine is noticeably higher than the curve for shortleaf pine until the older ages are reached when the two curves tend to become similar.

To determine if differences of root weights existed within root class 2, roots 0.50 to 0.10 inches in diameter, and age of stands an analysis of variance was made (Table 3).

It is evident from Table 3 that root class 2 does not give significant differences of root weights with age. Although the root-weight differences may be due to age, there is no statistical corroboration that the values are other than could be ascribed to chance.

Using the same procedure as before, the values for root class 2 were plotted over the reciprocal of age and a straight line fitted to the data by the method of least squares (Figs. 1C and 3C). From the straight line a smooth curve of root weight over age was obtained (Figs. 2D and 4D).

For the shortleaf pine type the curve of weight of roots in size class 2 over age of stands is nearly the same as that for root class 1. In the coarse sandy loam soil of this particular type the weight of roots in the smallest size class (less than 0.50 inch) and in size class 2 (0.50 to 0.10 inch) is approximately the same. However, in loblolly pine on the fine-textured soil the weight of roots in size class 2 is approximately one-third greater than that of class 1. The trend of the larger roots is similar to that of the small roots, increasing

**Table 3**

Analysis of variance of the weight of roots 0.05 to 0.10 inch in diameter in the surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Variation due to	Degrees of Freedom	Mean Square	F
Types	1	6.90	
Within types			
Between age classes	15	8.96	1.60
Error	17	5.53	
<b>Total</b>	<b>33</b>		



**Table 4**

Analysis of variance of the weight of all roots up to 0.10 inch in diameter in the surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Variation due to	Degrees of Freedom	Mean Square	F
Types	1	1.0	
Within types			
Between age classes	15	47.28	18.0*
Error	17	2.62	
Total	33		

\*Highly significant above the 1 percent level.

rapidly until 20 years and tapering off after stands were 30 years of age.

Differences in weight of all roots up to 0.10 inch in diameter were highly significant between age classes (Table 4).

For loblolly pine and shortleaf pine the values for root classes 1 and 2 combined were plotted over the reciprocal of age and a straight line fitted to the data by the method of least squares (Figs. 1E and 3E). The scattering of the original data is noted to be less than in the previous cases, and in the loblolly pine type the data are well represented by a straight line.

Smooth curves of root-weight over age were obtained from the straight line relationship (Figs. 2F and 4F). The curve for loblolly pine is higher than the curve for shortleaf pine throughout its entire length, indicating that the different soils of the two forest types determines, in part at least, the amount of small roots present in the surface soil.

There was no significant difference between stand age classes in the weights of roots larger than 0.10 inch in diameter.

Moisture equivalent determinations were made on the soil from each stand to find if the soils within each forest type were similar, and also to evaluate differences between the soils of the two forest types. Wilting percentages were obtained on the same soils by wilting oat seedlings. The moisture equivalents for the soil of the loblolly pine type were more than double those for the soil of the shortleaf pine type, indicating a higher water-holding capacity of the silt loam soils over the sandy loam soils. The amount of water available for root growth is represented by the difference between the wilting percentage and moisture equivalent of each soil. The fine-textured soil of the loblolly pine type has a much greater amount of water available for growth than does the coarse-textured

**Table 5**

Analysis of variance of the moisture equivalent of surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Variation due to	Degrees of Freedom	Mean Square	F
Types	1	2954.0	422*
Within types			
Between age classes	15	24.74	3.0**
Error	51	7.02	
Total	67		

\*Highly significant above the 1 percent level.

\*\*Significant at 1 percent level.

soil of the shortleaf pine type. The greater amount of available water may be the deciding factor in determining the relative amounts of small roots of each species.

In order to measure the variation of the soils within each type, analyses of variance were made on the moisture equivalent, wilting percentage, and available water data.

It is evident in Table 5 that the difference in moisture equivalent values under loblolly pine and shortleaf pine is highly significant. The difference in water-holding ability is due to the much greater amount of clay material in the soil of the loblolly pine series as compared to that of shortleaf pine.

The differences between moisture equivalents of the surface soil in various stands is attributed to greater incorporation of organic matter as the stands increase in age. Addition of organic matter to mineral soil increases water-holding characteristics in the same manner as does greater amounts of inorganic colloids. When compared to the large mean square value of types, that of between age

**Table 6**

Analysis of variance of wilting percentages of surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Variation due to	Degrees of Freedom	Mean Square	F
Types	1	54.0	186*
Within types			
Between age classes	15	2.2	7.5**
Error	51	0.28	
Total	67		

\*Very highly significant above 1 percent level.

\*\*Highly significant at 1 percent level.

classes is relatively small and serves as a measure of its contributing effect on the moisture equivalent.

The analysis of variance of the wilting percentage observations indicate differences between and within forest types of about the same magnitude as with the moisture equivalents (Table 6).

The magnitude of wilting percentage values is determined primarily by the amount of material of colloidal size in the soil. The wilting percentage of the silt loam soils supporting loblolly pine was approximately twice that of the sandy loam soil under shortleaf pine stands.

An analysis of variance of available water was made and gave results similar to those of wilting percentage and moisture equivalent (Table 7).

The results of the available water analysis show the difference in moisture retentiveness of the silt loam soil over the sandy loam soil. The much greater amount of water available for root and tree growth is shown in Figure 5. Available water values for the soil in loblolly pine stands 30 years old and shortleaf pine stands 40 years old are noticeably higher than in older stands. The deviations from the normal trend are evidently the result of higher amounts of fine clay fractions present, giving higher moisture equivalent values and resulting in more available water.

Table 8 shows the differences in moisture equivalent, wilting percentage, and available water of the surface soil between the loblolly pine and shortleaf pine types in a developmental and successional series. Table 9 represents the total amount of roots in the surface soil in a developmental and successional series of loblolly pine and shortleaf pine.

**Table 7**

Analysis of variance of the available water of surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Variation due to	Degrees of Freedom	Mean Square	F
Types	1	2241	489*
Within types			
Between age classes	15	13.8	3.0**
Error	51	4.6	
Total	67		

\*Very highly significant above 1 percent level.

\*\*Highly significant at 1 percent level.

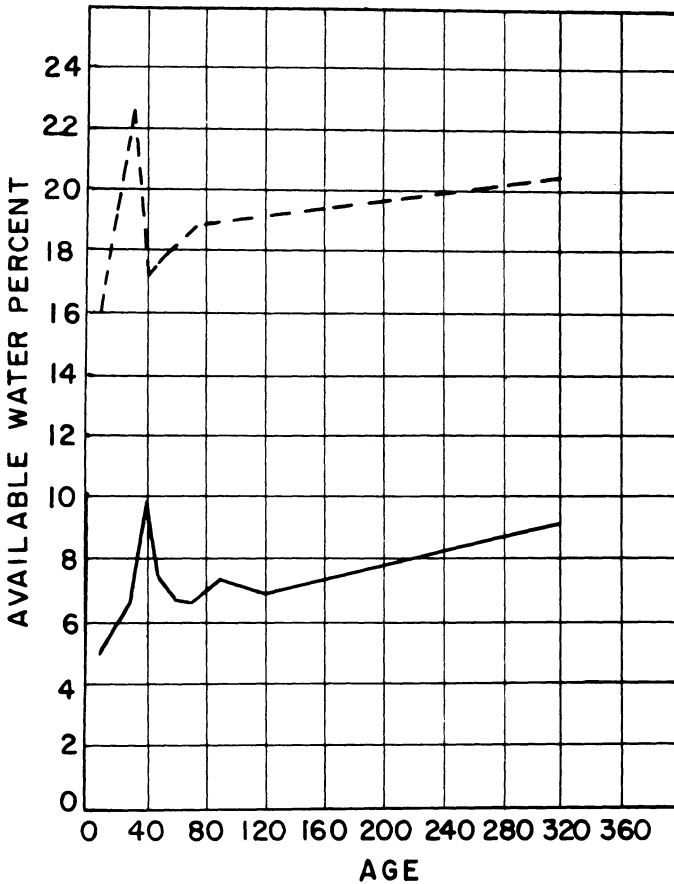


FIGURE 5. AVAILABLE WATER IN PERCENT OF OVEN DRY WEIGHT IN 7382 CC OF SURFACE SOIL ON AGE OF LOBLOLLY PINE AND SHORTLEAF PINE STANDS. THE DOTTED LINE REPRESENTS LOBLOLLY PINE AND THE SOLID LINE SHORTLEAF PINE STANDS.

Table 8

Moisture equivalent, wilting percentage, and available water values based on oven-dry weight basis of the surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Age	Species	Moisture Equivalent Percent	Wilting Percentage Percent	Available Water Percent	Age	Species	Moisture Equivalent Percent	Wilting Percentage Percent	Available Water Percent
10	Sh. P.				10	Lob. P.			
	R. 1	5.77	0.96	4.81		R. 1	22.42	2.40	20.02
	R. 2	6.75	1.53	5.22		R. 2	13.46	1.62	11.84
20	Sh. P.				20	Lob. P.			
	R. 1	7.5	1.38	6.12		R. 1	22.61	3.28	19.33
	R. 2	7.18	1.63	5.55		R. 2	23.58	4.04	19.54
30	Sh. P.				30	Lob. P.			
	R. 1	8.97	1.55	7.42		R. 1	26.22	5.60	20.62
	R. 2	6.81	1.02	5.79		R. 2	29.50	4.88	24.62
40	Sh. P.				40	Lob. P.			
	R. 1	16.38	3.27	13.11		R. 1	20.90	2.75	18.15
	R. 2	7.08	.71	6.37		R. 2	19.81	3.11	16.70
50	Sh. P.				50	Lob. P.			
	R. 1	8.10	1.45	6.65		R. 1	19.16	2.98	17.18
	R. 2	10.20	2.08	8.12		R. 2	21.46	3.24	18.22
60	Sh. P.								
	R. 1	8.42	1.25	7.17					
	R. 2	7.51	1.30	6.21					

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70	Sh. P.				70	Lob. P.			
	R. 1	9.96	2.42	7.54		R. 1	21.77	3.56	18.21
	R. 2	7.12	1.03	6.09		R. 2	22.57	3.23	19.34
90	Sh. P.								
	R. 1	8.76	1.50	7.26					
	R. 2	8.98	1.53	7.45					
100	Sh. P.								
	R. 1	7.91	.94	6.97					
	R. 2	8.15	1.19	6.96					
320	WO-BO-RO				320	WO-BO-RO			
	R. 1	12.64	3.14	9.50		R. 1	28.85	4.01	24.84
	R. 2	11.86	2.66	9.20		R. 2	18.70	2.31	16.39

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Table 9

Weights of all roots in the surface soil in a developmental and successional series of shortleaf pine and loblolly pine.

Age	Species	Root Class Diameter inch	Rep. 1 grams	Rep. 2 grams	Age	Species	Root Class Diameter inch	Rep. 1 grams	Rep. 2 grams
10	Lob. P.	.05	3.10	3.86	10	Sh. P.	.05	2.66	2.53
		.05-.10	3.5	4.55			.05-.10	1.74	2.53
		.1-.3	1.97	4.87			.1-.3	3.90	3.34
		.3-.5	.....	3.65			.3-.5	2.06	13.05
							.5-1.0	1.72	.....
20	Lob. P.	.05	3.66	2.95	20	Sh. P.	.05	3.42	4.02
		.05-.10	4.88	3.21			.05-.10	4.32	3.67
		.1-.3	1.71	5.78			.1-.3	10.16	9.35
		.3-.5	3.26	7.86			.3-.5	1.58	2.55
							.5-1.0	2.56	.....
30	Lob. P.	.05	5.34	6.33	30	Sh. P.	.05	3.41	4.02
		.3-.5	1.50	6.22			.05-.10	3.95	2.13
		.1-.3	3.79	5.93			.1-.3	4.33	3.50
		.05-.10	5.13	7.13			.3-.5	.....	4.99
40	Lob. P.	.05	5.35	5.44	40	Sh. P.	.05	4.20	3.76
		.5-1.0	15.33	.....			.05-.10	5.41	4.71
		.3-.5	3.99	4.20			.1-.3	4.72	4.75
		.1-.3	6.11	4.87			.3-.5	5.40	3.56
		.05-.10	5.23	6.10			.5-1.0	5.39	8.10
		.5-1.0	.....	25.31					

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50	Lob. P	.05	4.93	4.66	50	Sh. P.	.05	5.35	4.21
		.05-.10	6.65	5.37			.05-.10	5.13	5.21
		.1-.3	7.90	5.72			.1-.3	3.79	7.78
		.3-.5	2.69	4.61			.3-.5	1.50	4.31
		.5-1.0	2.34	8.33			.5-1.0	.....	30.83
					60	Sh. P.	.05	3.24	3.13
							.05-.10	5.22	2.81
							.1-.3	4.08	4.00
							.3-.5	4.61	2.60
							.5-1.0	.....	14.69
70	Lob. P.	.05	11.17	3.78	70	Sh. P.	.05	4.60	6.10
		.05-.10	10.16	4.80			.05-.10	5.36	3.19
		.1-.3	5.14	4.37			.1-.3	9.45	3.75
		.3-.5	8.37	8.22			.3-.5	13.03	5.85
		.5-1.0	25.24	35.44			.5-1.0	.....	14.69
					90	Sh. P.	.05	7.40	9.59
							.05-.10	9.20	7.38
							.1-.3	10.03	13.56
							.3-.5	8.90	8.78
							.5-1.0	9.53	17.33
					100	Sh. P.	.05	6.96	6.03
							.05-.10	6.15	4.08
							.1-.3	13.43	9.40
							.3-.5	2.60	12.64
							.5-1.0	9.53	17.33
320	WO-BO-RO	.05	5.44	8.18	320	WO-BO-RO	.05	11.43	6.91
		.05-.10	7.13	10.45			.05-.10	11.22	8.63
		.1-.3	5.93	7.77			.1-.3	17.19	16.99
		.3-.5	6.22	11.90			.3-.5	9.83	15.24
		.5-1.0	25.31	6.75			.5-1.0	.....	14.69
	fine texture					coarse texture			

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TREE ROOTS IN PIEDMONT SOILS

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### SUMMARY

1. There is a positive correlation between the age of forest stands and the amount of roots up to 0.10 inch in diameter measured in terms of oven-dry weight of roots.

2. There is a rapid increase in the amount of roots up to 0.10 inch in diameter until stands reach approximately 20 years of age when the amount begins to increase at a slower rate. After stands are approximately 30 years of age the amount of roots increases slowly and reaches a near constant value.

3. Fine-textured soils have higher moisture retention than coarse-textured soil, and as a consequence have more water available for root development. There is a significantly greater amount of roots produced in the fine soil over the coarse soil as measured by dry weight of roots.

4. After about 60 years of age the surface soil in forest stands is almost saturated with fine roots and this may be a limiting factor in the establishment of forest reproduction that has a naturally inflexible root system. Invasion of shallow-rooted species under mature forests may be controlled to some extent for the above reason.

5. As forest stands increase in age there is an increased amount of organic matter incorporated into the soil. Consequently, the waterholding capacity is increased and conditions for growth of roots in the surface soil is made more favorable.

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